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APPLICATION FOR LETTERS PATENT

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**RF Powered Plasma Enhanced Chemical Vapor
Deposition Reactor and Methods Of Effecting
Plasma Enhanced Chemical Vapor Deposition**

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1 TECHNICAL FIELD

2 This invention relates to RF powered plasma enhanced chemical
3 vapor deposition reactors and methods of effecting plasma enhanced
4 chemical vapor deposition.

5 BACKGROUND OF THE INVENTION

6 Semiconductor processing often involves the deposition of films or
7 layers over or on a semiconductor substrate surface which may or may
8 not have other layers already formed thereon. One manner of effecting
9 the deposition of such films or layers is through chemical vapor
10 deposition (CVD). CVD involves a chemical reaction of vapor phase
11 chemicals or reactants that contain the desired constituents to be
12 deposited on the substrate or substrate surface. Reactant gases are
13 introduced into a reaction chamber or reactor and are decomposed and
14 reacted at a heated surface to form the desired film or layer.

15 There are three major CVD processes which exist and which may
16 be utilized to form the desired films or layers. These are: atmospheric
17 pressure CVD (APCVD), low pressure CVD (LPCVD), and plasma
18 enhanced CVD (PECVD). The former two processes (APCVD and
19 LPCVD) are characterized by their pressure regimes and typically use
20 thermal energy as the energy input to effect desired chemical reactions.
21 The latter process (PECVD) is characterized by its pressure regime and
22 the method of energy input.

In PECVD systems, rather than relying on thermal energy to initiate and sustain chemical reactions, RF-induced glow discharge is used to transfer energy to the reactant gases. Such allows the substrate to remain at a lower temperature than the APCVD and LPCVD systems. Lower substrate temperatures are desirable in some instances because some substrates do not have the thermal stability to accept coating by the other methods. Other desirable characteristics include that deposition rates can be enhanced and films or layers with unique compositions and properties can be produced. Furthermore, PECVD processes and systems provide other advantages such as good adhesion, low pinhole density, good step coverage, adequate electrical properties, and compatibility with fine-line pattern transfer processes.

One problem, however, associated with deposition processing including PECVD processing stems from non-uniform film or layer coverage which can result especially in high aspect ratio topographies. For example, a problem known as "bread-loafing" or cusping can typically occur in deposition processing. Such normally involves undesirable non-uniform build-up of deposited material forming what appear as key hole spaces between features on a substrate. One prior art solution has been to conduct multiple depositions of very thin layers with intervening plasma etching treatments. The intervening plasma etching serves to remove or cut away the cusps to form a more uniformly applied layer. Thereafter, repeated depositions and etchings are conducted until the desired coverage is achieved. It is desirable to

1 improve upon the quality of film or layer deposition in PECVD
2 processes and reactors.

3 This invention grew out of concerns associated with improving
4 PECVD processing systems and methods. This invention also grew out
5 of concerns associated with improving the advantages and characteristics
6 associated with PECVD systems, including those advantages and
7 characteristics mentioned above.

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9 SUMMARY OF THE INVENTION

10 Plasma enhanced chemical vapor deposition (PECVD) reactors and
11 methods of effecting the same are described. In accordance with a
12 preferred implementation, a reaction chamber includes first and second
13 electrodes operably associated therewith. A single RF power generator
14 is connected to an RF power splitter which splits the RF power and
15 applies the split power to both the first and second electrodes.
16 Preferably, power which is applied to both electrodes is in accordance
17 with a power ratio as between electrodes which is other than a 1:1
18 ratio. In accordance with one preferred aspect, the reaction chamber
19 comprises part of a parallel plate PECVD system. In accordance with
20 another preferred aspect, the reaction chamber comprises part of an
21 inductive coil PECVD system. The power ratio is preferably adjustable
22 and can be varied. One manner of effecting a power ratio adjustment
23 is to vary respective electrode surface areas. Another manner of
24 effecting the adjustment is to provide a power splitter which enables the

1 output power thereof to be varied. PECVD processing methods are
2 described as well.

3

4 **BRIEF DESCRIPTION OF THE DRAWINGS**

5 Preferred embodiments of the invention are described below with
6 reference to the following accompanying drawings.

7 Fig. 1 is a block diagram of a plasma enhanced chemical vapor
8 deposition (PECVD) reactor system in accordance with preferred
9 embodiments of the present invention.

10 Fig. 2 shows one implementation of one preferred PECVD reactor
11 for use in the Fig. 1 system.

12 Fig. 3 shows another implementation of another preferred PECVD
13 reactor for use in the Fig. 1 system.

14 Fig. 4 shows one implementation of one preferred power splitter
15 for use in the Fig. 1 system.

16 Fig. 5 shows another implementation of another preferred power
17 splitter for use in the Fig. 1 system.

18 Fig. 6 is a flow chart illustrating preferred processing methods for
19 use in connection with the preferred embodiments of the present
20 invention.

1 DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

2 This disclosure of the invention is submitted in furtherance of the
3 constitutional purposes of the U.S. Patent Laws "to promote the
4 progress of science and useful arts" (Article 1, Section 8).

5 Referring to Fig. 1, a plasma enhanced chemical vapor deposition
6 (PECVD) reactor system is shown in block diagram form generally
7 at 10. System 10 includes a gas supply unit 12, a chemical vapor
8 deposition reactor 14, an RF power splitter 16 and an RF power
9 generator 18.

10 Gas supply unit 12 can supply one or more gaseous reactants into
11 reactor 14 for processing in accordance with the invention. Typically,
12 such systems use an RF-induced glow discharge to transfer energy into
13 the reactant gases. Subsequently, free electrons are created within the
14 discharge region which gain energy so that when they collide with gas
15 molecules, gas-phase dissociation and ionization of the reactant gases
16 occurs. Accordingly, energetic species are then absorbed on a
17 workpiece or substrate.

18 PECVD reactor 14 defines a processing chamber or volume
19 interiorly of which processing takes place in accordance with the
20 invention. In a first preferred implementation, reactor 14 comprises a
21 parallel plate reactor. Such parallel plate reactor can be configured to
22 process only one semiconductor workpiece or wafer. Alternately, such
23 reactor can be configured to process more than one semiconductor
24 workpiece or wafer. In a second preferred implementation, reactor 14

1 comprises an inductive coil PECVD reactor. Both preferred
2 implementations are discussed below in more detail in connection with
3 Figs. 2 and 3.

4 Referring still to Fig. 1, RF power splitter 16 in the illustrated
5 and preferred embodiments splits or otherwise divides RF input power
6 which is provided by RF power generator 18 into RF power components
7 which are thereafter used to power separate reactor electrodes. In a
8 preferred implementation, such power is split or divided in accordance
9 with a selected power ratio which can be manipulated by an operator
10 of the system. Preferably, such ratio is one which is other than a
11 direct 1:1 ratio. Such split or divided power is subsequently applied via
12 lines or terminals 15, 17 to individual electrodes comprising a part of
13 reactor 14, as will be described below.

14 Referring to Fig. 2, a PECVD reactor according to a first
15 preferred implementation is set forth generally at 20. Reactor 20
16 preferably comprises a capacitive parallel plate reactor which may or
17 may not be configured to process more than one workpiece or wafer.
18 Preferably, reactor 20 defines a processing chamber 21 which includes
19 a first electrode 22 disposed internally thereof. Electrode 22 is
20 configured for supporting at least one semiconductor workpiece in the
21 form of semiconductor wafer W. The term "supporting" as such is used
22 in this document and in connection with the first electrode in each of
23 the embodiments is intended to mean holding or positioning one or
24 more semiconductor workpieces in a desired orientation so that chemical

vapor deposition can take place. Accordingly, semiconductor workpieces can be supported, held or otherwise positioned in orientations other than the shown horizontal position. Moreover, although the invention is discussed in the context of a system which includes only two electrodes, it is to be understood that the invented reactors and methods can find use in systems which are not necessarily limited to only two electrodes. First electrode 22 includes a first electrode surface area 24 upon which wafer W rests for processing in accordance with the invention. First electrode 22, in the illustrated and preferred embodiment, is a susceptor which supports the workpiece. Processing chamber 21 includes a second electrode 26 which is disposed internally thereof. A gap exists between the electrodes such that the electrodes are suitably spaced from one another. In the illustrated and preferred embodiment, second electrode 26 constitutes a shower head electrode which is positioned operably adjacent the susceptor and configured to provide gaseous reactants into the chamber from gas supply unit 12 (Fig. 1). Gaseous reactants can, however, be introduced into the reactor in other ways. Preferably, second electrode 26 defines a second electrode surface area 28 which is different from and preferably smaller than first electrode surface area 24. That is, first electrode surface area 24 is larger than the second electrode surface area 28. Such surface area differential between the first and second electrodes enables an RF power differential to be developed as between the electrodes

1 using only a single RF power source. Such will become apparent from
2 the discussion below.

3 Referring still to Fig. 2, lines 15 and 17 are respectively operably
4 connected to first and second electrodes 22, 26. Such lines connect RF
5 power generator 18 (Fig. 1) to the respective electrodes through RF
6 power splitter 16 which, for the purpose of the ongoing discussion, is
7 operatively interposed between the RF power generator and both the
8 susceptor and the shower head electrodes. Preferably, RF power
9 generator 18 comprises a single generator power source which is
10 operatively associated with the processing chamber and configured to
11 provide RF power to the RF power splitter which, in turn, provides RF
12 power to both the susceptor and the shower head according to a
13 selected power ratio which is discussed below in more detail. Such
14 represents a novel departure from prior PECVD reactors wherein only
15 the shower head electrode was powered by an RF power source with
16 the susceptor electrode being grounded. The illustrated single RF
17 power generator is preferably configured to provide RF power to the
18 electrodes which is effective to both develop a plasma processing
19 environment within the processing chamber and provide a desired bias
20 relative to the semiconductor workpiece. For example, maintaining the
21 electrodes at the preferred power differential facilitates acceleration of
22 ions or ionic species toward the subject workpiece or wafer which
23 enhances conformal coverage, particularly in high aspect ratio

1 topographies. Furthermore, greater uniformity in film or layer
2 composition, as well as greater film or layer purity levels are possible.

3 Referring to Fig. 3, and in accordance with another preferred
4 implementation of the invention, a different type of PECVD reactor 30
5 is set forth. Such reactor comprises an inductive coil PECVD reactor.
6 Reactor 30 comprises a processing chamber 31 interiorly of which
7 chemical vapor deposition processing can take place in accordance with
8 the invention. A first electrode 32 is disposed internally of the reactor
9 and is configured for supporting at least one semiconductor workpiece,
10 such as wafer W thereon. First electrode 32 is powered by the
11 preferred single RF power generator 18 (Fig. 1). It is possible for
12 more than one wafer to be processed in accordance with the invention.
13 A second electrode 34 is provided externally of processing chamber 31
14 and comprises a plurality of coils which are powered by the same
15 preferred single RF power generator.

16 Referring to both Figs. 2 and 3, such comprise PECVD reactors
17 which include respective electrodes both of which are powered by a
18 single RF power generator or supply. According to a first
19 implementation, both electrodes are disposed internally of the processing
20 chamber (Fig. 2). According to second preferred implementation, at
21 least one of the electrodes is disposed externally of the processing
22 chamber (Fig. 3). Both electrodes in both preferred implementations
23 are powered from and by a single RF powered generator, such as
24 generator 18 in Fig. 1. As mentioned above, this represents a novel

1 departure from previous PECVD reactors where both electrodes were
2 not powered with RF power from a common, single RF power source.

3 Referring to Fig. 4, a preferred RF power splitter is set forth
4 generally at 36. Power splitter 36 in the illustrated and preferred
5 embodiment comprises a transformer 38 which includes an input side or
6 primary windings 40 and an output side or secondary windings 42.
7 Input side 40 is operatively coupled or connected to RF power
8 generator 18 (Fig. 1) via a coaxial cable 44 and receives power
9 generated thereby. Output side 42 includes at least two output
10 terminals 15, 17 which are operatively coupled or connected to
11 respective first and second electrodes 22, 26 (in the Fig. 2 PECVD
12 reactor) or first and second electrodes 32, 34 (in the Fig. 3 PECVD
13 reactor). In a preferred implementation, the output side has no more
14 than two terminals, and the first and second electrodes constitute the
15 only processing chamber electrodes which are powered thereby. Power
16 splitter 36 splits input power provided by power generator 18 into first
17 and second power components which are thereafter provided to the
18 respective electrodes. The output side of the preferred transformer
19 provides power to each of the first and second electrodes in accordance
20 with a selected power ratio which is discussed below. A suitable
21 matching network 46 is provided for impedance matching purposes.
22 Such networks typically include various capacitative and inductive
23 components which are configured for impedance matching. Such are
24 represented in block diagram form in box 46.

In accordance with a preferred aspect of the invention, RF power splitter 36 comprises a center tapped transformer in which the output power provided to the respective first and second electrodes is substantially equal in magnitude. Such is desirable when power splitter 36 is used in connection with the PECVD reactor of Fig. 2. In such circumstances, it has been found that the ratio of power which is applied to the electrodes is proportional to surface areas 24, 28 of electrodes 22, 26. Hence, by changing or manipulating the subject surface areas, one can manipulate or select the power ratio and affect the magnitudes of the first and second power components which are "seen" by the respective electrodes to which such power components are applied. In the illustrated and preferred embodiment, such surface areas are different from one another, with the susceptor surface area being larger than the shower head surface area. Such enables a power differential to be developed according to a definable relationship. Such relationship consists of a predefined relative magnitude which is directly proportional to the inverse ratio of the 4th power of the areas of the electrodes. Put another way, by varying the relative surface area ratios as between the susceptor and shower head, a variation in power applied thereto can be effectuated. In the illustrated and preferred embodiment, second electrode or shower head 26 has a surface area which is less than or smaller than the surface area of the first electrode or susceptor 22. Such results in a higher magnitude of power being applied to the shower head than is applied to the susceptor.

1 This advantageously allows deposition of reactants introduced into
2 chamber 21 in a preferred manner by causing highly energetic species
3 to be drawn toward and in the direction of the electrode supporting the
4 workpiece.

5 Referring to Fig. 5, an alternate preferred power splitter is set
6 forth generally at 36a. Such alternate preferred power splitter enables
7 the desired power differential to be developed without regard to and
8 independently of the surface area ratios between the subject electrodes,
9 whether such electrodes be those associated with the Fig. 2 reactor or
10 the Fig. 3 reactor. Like numbers from the first described power
11 splitter are utilized where appropriate, with differences being indicated
12 with the suffix "a" or with different numerals. Accordingly, power
13 splitter 36a comprises an input side 40 which is operatively coupled with
14 RF generator 18 (Fig. 1) and an output side 42a which is operatively
15 coupled with one of the preferred reactors 20, 30. Such enables, but
16 does not require reactor 20 of Fig. 2 to have a susceptor electrode and
17 a shower head electrode with respective surface areas which are more
18 nearly equal. Power splitter 36a advantageously allows the selected
19 power ratio to be adjusted in a manner which varies the power
20 supplied to the electrodes. Accordingly, and in the illustrated and
21 preferred embodiment, the RF power splitter comprises a transformer
22 having a plurality of secondary windings 42a. Such are desirably
23 variably groundable as is indicated at 48.

Referring still to Fig. 5 and for illustrative purposes only, output side 42a is shown as comprising nine windings. By selectively grounding different windings or coils, different ratios of power are provided to the shower head and susceptor electrodes. More specifically for example, if the number 2 coil or winding is grounded as shown, then the first electrode, either electrode 22 (Fig. 2) or 32 (Fig. 3) receives two ninths (2/9) or 22.2% of the input power from the power generator. Accordingly, the second electrode, either electrode 26 (Fig. 2) or 34 (Fig. 3) receives seven ninths (7/9) or 77.8% of the input power. Relatedly, if the number 7 coil or winding is grounded, the distribution of power is reversed, i.e. the first electrode receives seven ninths (7/9) of the input power and the second electrode receives two ninths (2/9) of the input power. As such, the provision of power to the preferred electrodes can be varied to accommodate different processing regimes. In the illustrated and preferred Fig. 5 embodiment, power splitter 36a is able to be adjusted by an end user for varying the selected power ratio to accommodate different processing regimes. Such processing regimes preferably provide a greater quanta of power to the second electrode rather than the first electrode. Alternately, the power provided to the electrode which is closest in proximity to the semiconductor workpiece is less than the power provided to the electrode which is spaced apart from such workpiece.

Accordingly, two separate and preferred power splitters have been described. The first of which (Fig. 4) is advantageous for producing

1 output power having magnitudes which are substantially the same. Such
2 power splitter is suited for use in reactors, such as reactor 20 of Fig. 2
3 in which the ultimate magnitude of power supplied to the illustrated
4 electrodes can be adjusted by varying the surface area ratios of the
5 subject electrodes. Such power splitter may also be used in connection
6 with reactor 30. Alternately, and equally as preferred, a power
7 splitter 36a (Fig. 5) allows for the output power to be variably adjusted
8 to a selected power ratio which is suitable for use in reactors, such as
9 reactor 20 of Fig. 2, in which electrodes do not have or are not
10 required to have a meaningful variance between the electrode surface
11 areas. Additionally, such power splitter can be and preferably is
12 utilized in connection with reactor 30 of Fig. 3.

13 Referring to Fig. 6, a representative flow chart of a preferred
14 method of processing semiconductor workpieces in connection with the
15 above described reactors is set forth generally at 100. The preferred
16 methodology involves first at step 110 placing a semiconductor workpiece
17 in a selected one of the above-described PECVD reactors. According
18 to a preferred implementation, a susceptor is provided for supporting
19 the workpiece internally of the processing chamber. In accordance with
20 the Fig. 2 embodiment, a shower head electrode 26 is provided operably
21 adjacent the susceptor and is configured for providing gaseous reactants
22 into chamber. According to the Fig. 3 embodiment, at least one of the
23 reactor electrodes is disposed externally of the chamber. At step 112,
24 gaseous reactants are provided into the reactor chamber whereupon, at

1 step 114, RF power from the preferred single or common RF power
2 source is provided. At step 116, the provided RF power is split into
3 first and second power components which are selectively provided to the
4 respective electrodes discussed above. For example, a first power
5 component at step 118 is applied to a first of the electrodes. At
6 step 120, a second of the power components is applied to a second of
7 the electrodes. Preferably, the applied power components are different
8 from one another with such difference stemming from either a variation
9 in electrode surface areas (Fig. 2) or a variably selectable grounding of
10 the secondary or output side 42a (Fig. 5) of power splitter 36a.
11 According to a preferred implementation, a transformer output coil,
12 other than the center coil, can be selectively grounded for varying the
13 relative magnitudes of the power components. Such is indicated as an
14 optional step 122 wherein an individual user may select a desired power
15 ratio as between reactor electrodes. At processing step 124, and with
16 the desired power ratio being applied to the selected electrodes, the
17 semiconductor workpiece is processed to effect chemical vapor deposition
18 thereupon. At step 126, processing is complete and a next workpiece
19 may be processed in accordance with the above description.

20 In compliance with the statute, the invention has been described
21 in language more or less specific as to structural and methodical
22 features. It is to be understood, however, that the invention is not
23 limited to the specific features shown and described, since the means
24 herein disclosed comprise preferred forms of putting the invention into

1 effect. The invention is, therefore, claimed in any of its forms or
2 modifications within the proper scope of the appended claims
3 appropriately interpreted in accordance with the doctrine of equivalents.

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